

Vibration Testing of Electrical Cables To Quantify Loads at Tie-Down Locations

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Electrical cables are used extensively in rockets for power and data transfer

Cables are required to survive exposure to all flight loading environments, random vibration typically being the dominant environment

Connections between electrical cables and components (avionics boxes, data recorders, batteries, etc.) are typically certified by test as part of component qualification

Cables must be tied down to structure at regular intervals to prevent large displacements and loads during flight

Hardware used at cable tie-down locations (cable ties, P-clamps) are typically certified by analysis

Standard methods (Mile's equation with amplification factor (Q) of 10) for defining static equivalent component loads are overly conservative for electrical cables

- Cables are highly damped with low natural frequencies
- Conservative loads result in negative structural margins on cable tie-down hardware

Certification of electrical cable tie-down hardware requires a unique approach for developing design loads that account for cable dynamic characteristics (damping and frequency)

Introduction – Outline



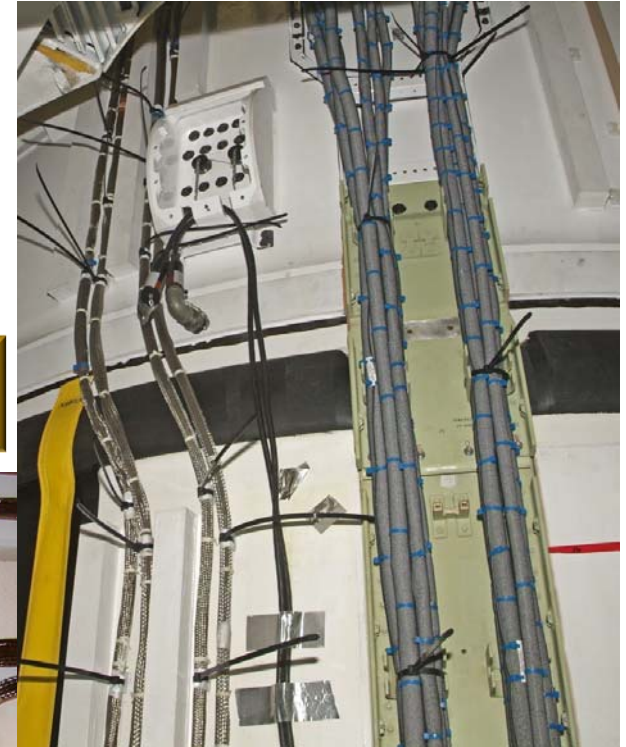
Purpose: This presentation summarizes vibration testing of electrical cables and the methodology for calculating loads at cable tie-down points that was developed from this test data

This effort was performed under contract number NNM07AA75C with NASA-MSFC

Outline

- Test objectives
- Test configurations
- Test instrumentation
- Test run matrix
- Test fixture survey
- Data processing
- Cable natural frequency and damping
- Development of load methodology
- Load methodology at cable tie-down points
- Conclusions and forward work

Cable routing in flight hardware



Test Objectives



Objectives of preliminary cable vibration testing:

- Check out test fixture and instrumentation in preparation for final cable testing
- Identify most significant variables (from list below) that should be included in final cable testing
 - Temperature
 - Cable thermal jacking
 - Cable tautness
 - Cable diameter
 - Cable mass
 - Cable stiffness
 - Cable tie-down spacing
 - Cable orientation relative to excitation
 - Type of attach hardware (P-clamp, triple P-clamp, zip tie, rigid connection, etc.)



Taut and slack

Range of diameters and thermal jacking options



Rigid and zip tie attach

Temperature conditioning



Test Configurations

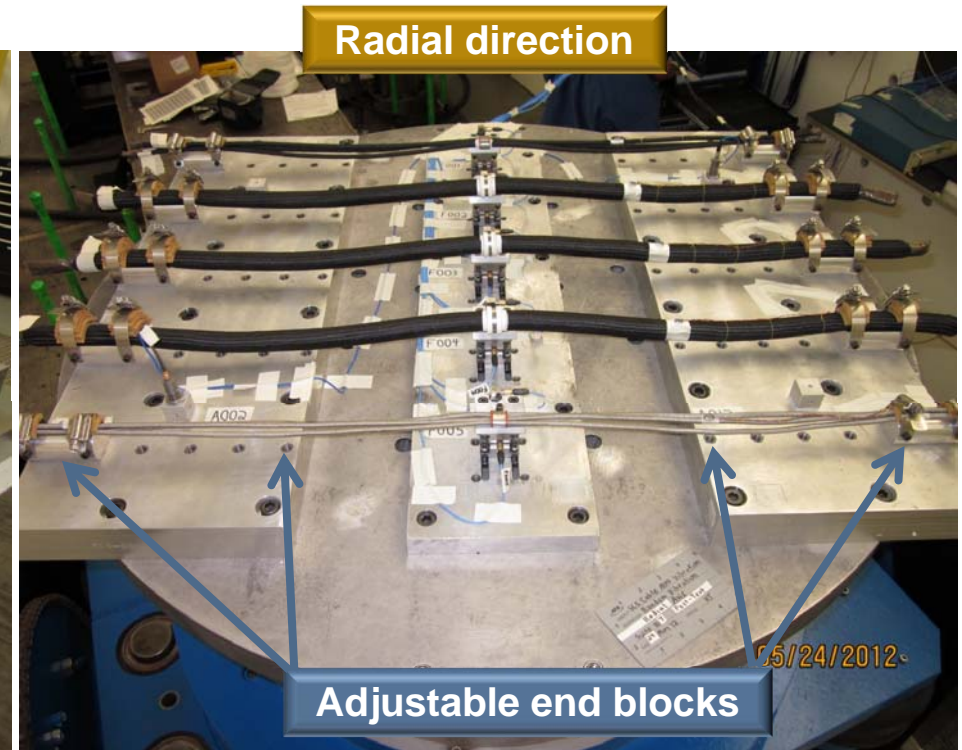
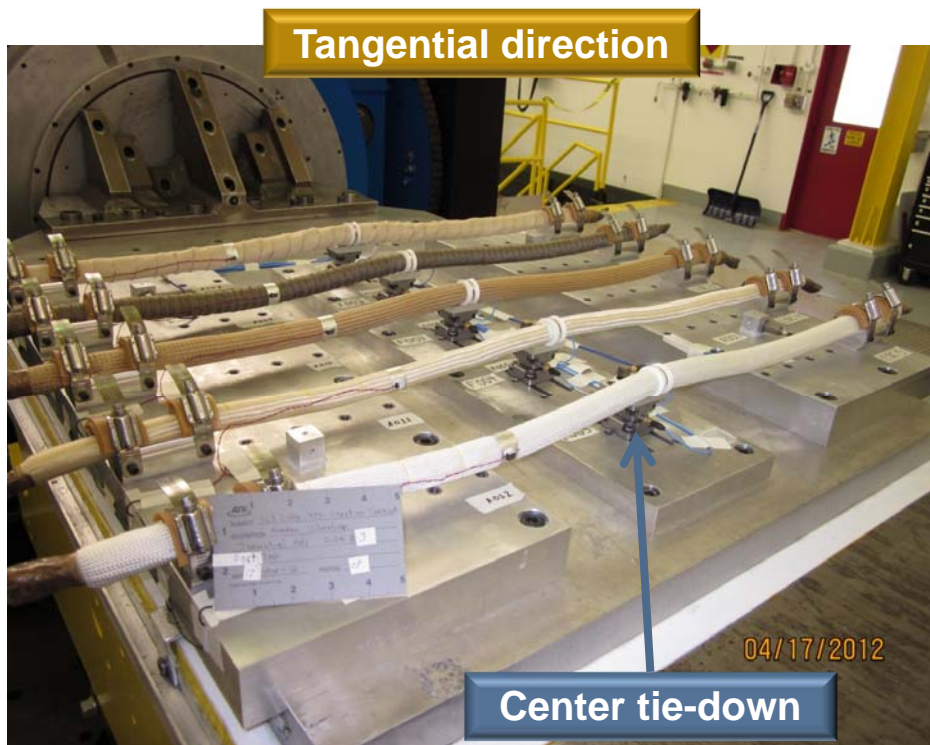


Longitudinal and tangential directions tested on vibration slip table (left photo)

Radial direction tested in vertical direction with expander head installed (right photo)

Up to 5 cable configurations tested simultaneously

Fixture allows tie-down spacing adjustments



Two control accelerometers on blocks attached to fixture side plates

- PCB Piezotronics 353B04 accelerometer
- Amplitude: ± 500 g
- Frequency: 1 to 7,000 Hz

Load cells used to measure load transmitted through cable attach

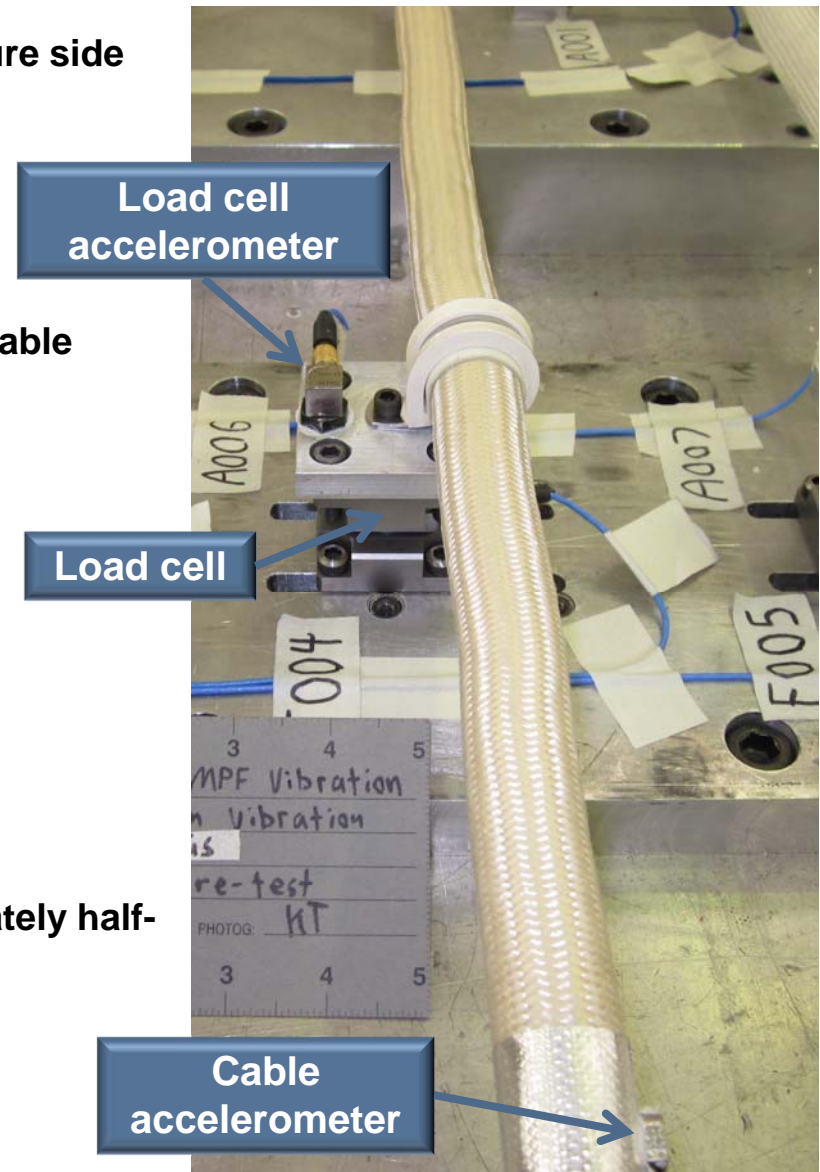
- PCB Piezotronics 261A01 force sensors
- Amplitude: $\pm 1,000$ lbf axial, ± 500 lbf lateral
- Frequency: 0.01 to 10,000 Hz

Accelerometer mounted to top of load cell to measure acceleration level at input to cable

- PCB Piezotronics 356A33 accelerometer
- Amplitude: ± 500 g
- Frequency: 2 to 7,000 Hz

Small accelerometer mounted to each cable approximately half-way to end point

- PCB Piezotronics 352A72 accelerometers
- Amplitude: ± 500 g
- Frequency: 0.5 to 4,500 Hz

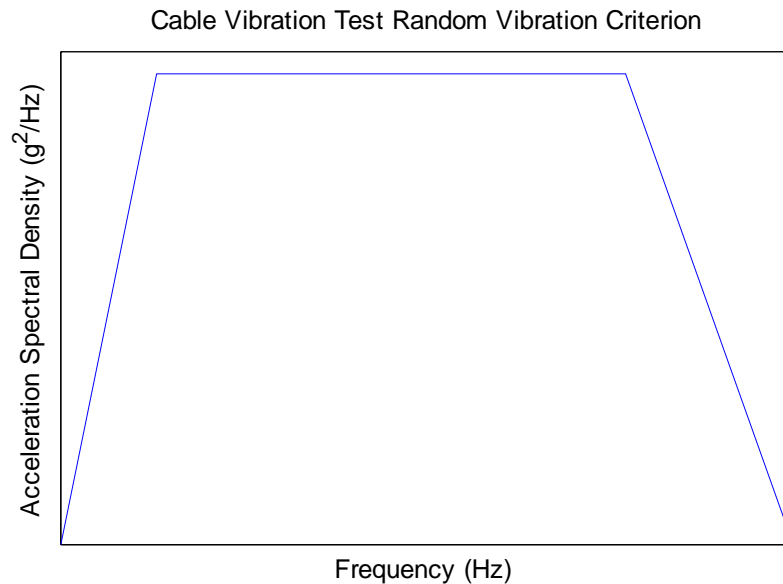


Run matrix included 19 test setups (suites) with up to 5 cable configurations per setup

Input vibration spectrum shown below

- Vibration levels ramped up from -8 dB to full level in steps of 1 dB with data collected at each step

Input vibration spectrum



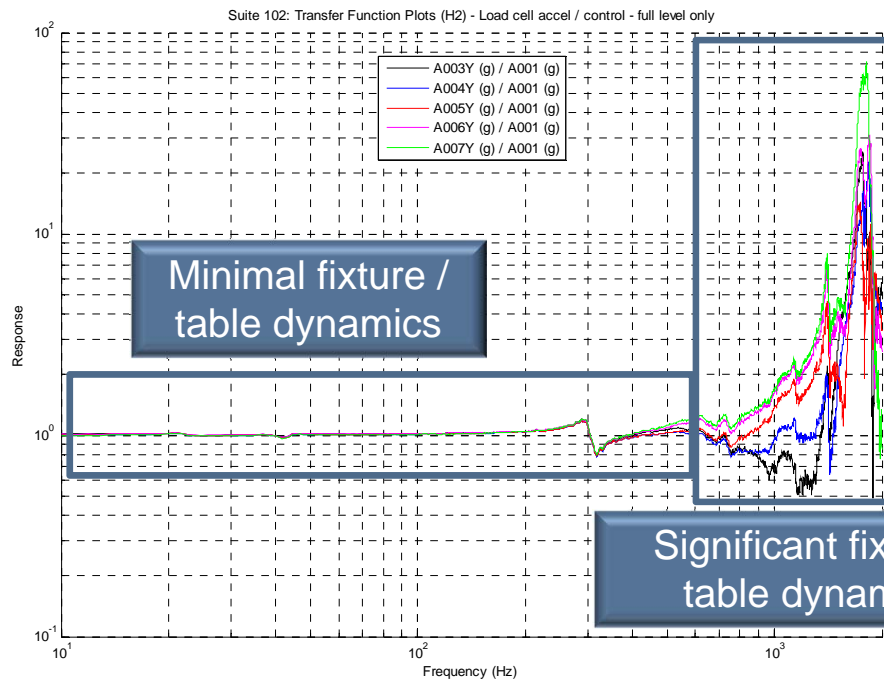
Test Fixture Survey



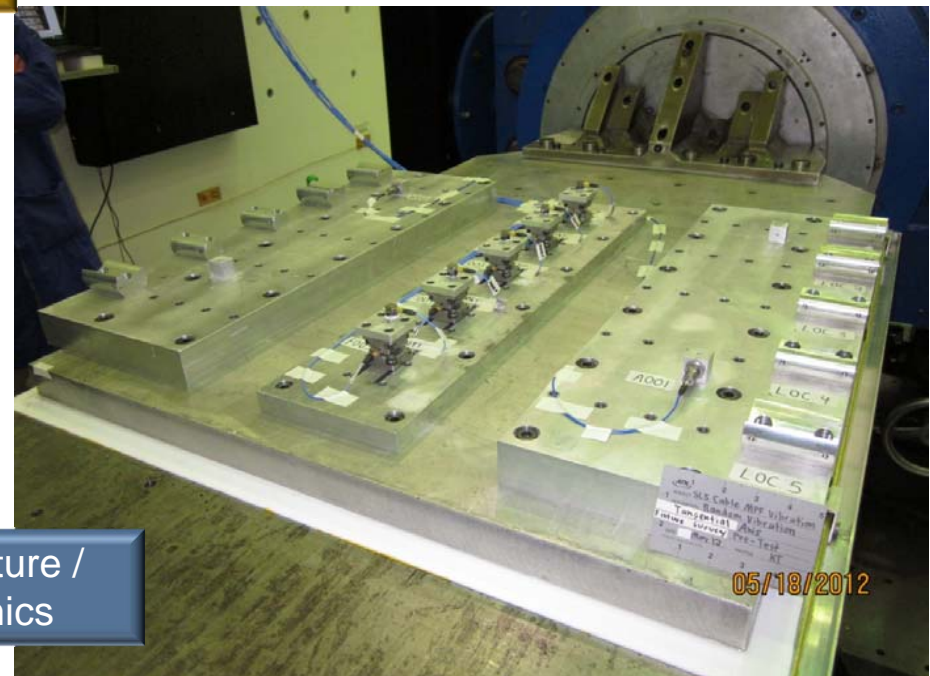
Random vibration fixture survey (no cables installed) was conducted in each direction

- Surveys showed that table / fixture frequencies begin to affect data in 400 to 600 Hz range

Survey transfer functions Load cell accelerometer / control accelerometer



Fixture survey setup

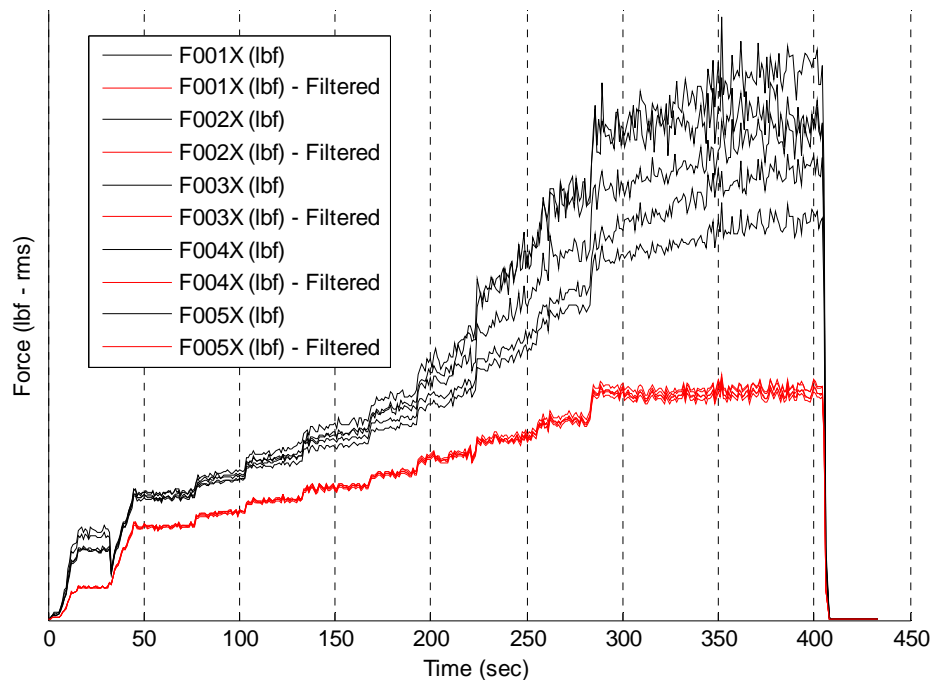


Load and acceleration RMS plots (filtered and unfiltered) show that table / fixture dynamics produce significant high-frequency levels as well as variation in levels at different locations on the table

6-pole, 600 Hz, low-pass Butterworth filter applied to focus analysis on lower frequency data where cable natural frequencies are observed

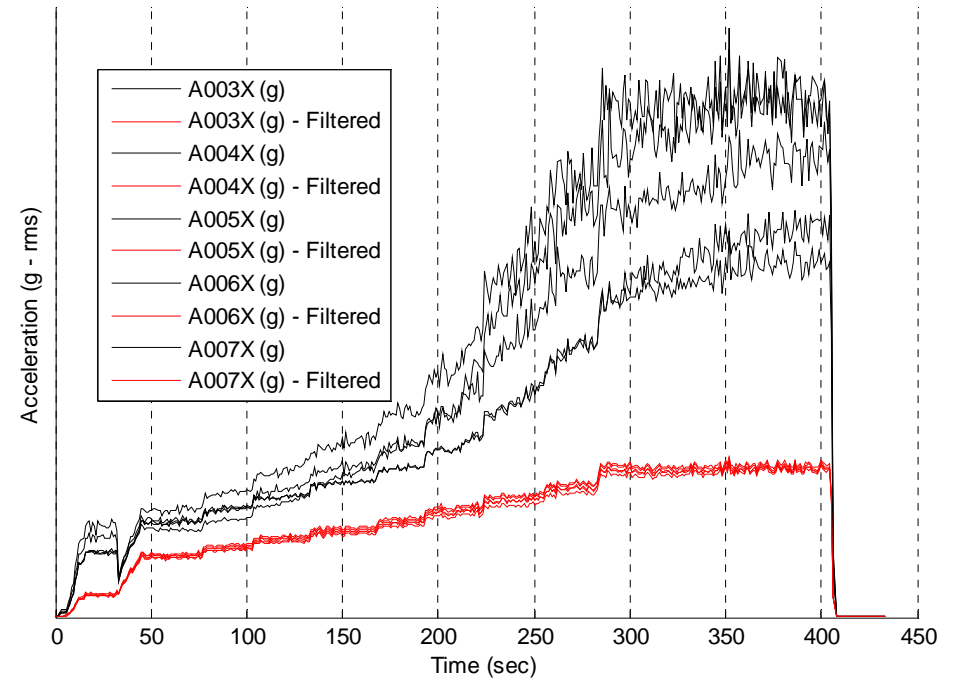
Load RMS plot

Suite 101: Time History RMS Plots



Load cell accelerometer RMS plot

Suite 101: Time History RMS Plots



600 Hz low-pass filter removed table / fixture dynamics

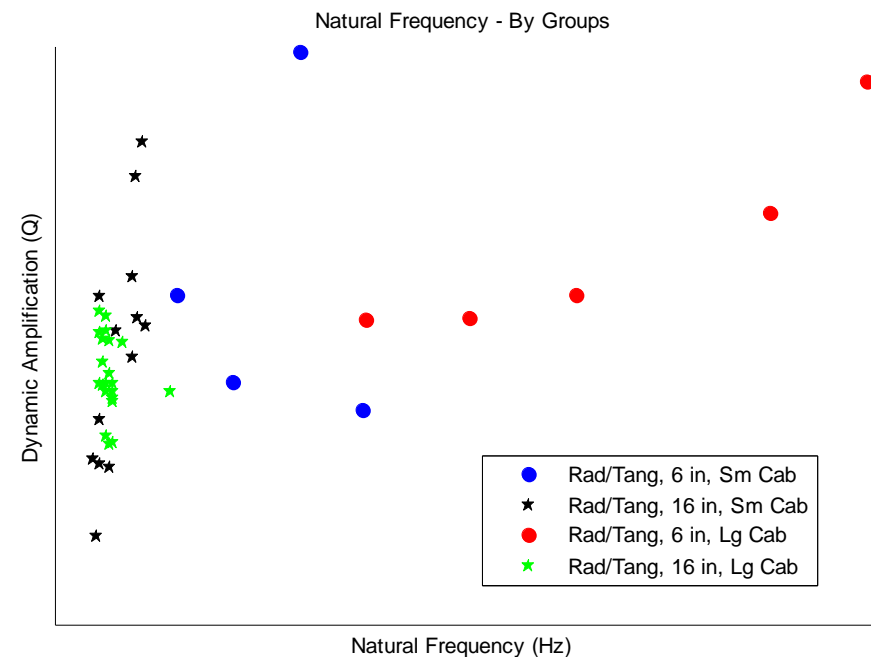
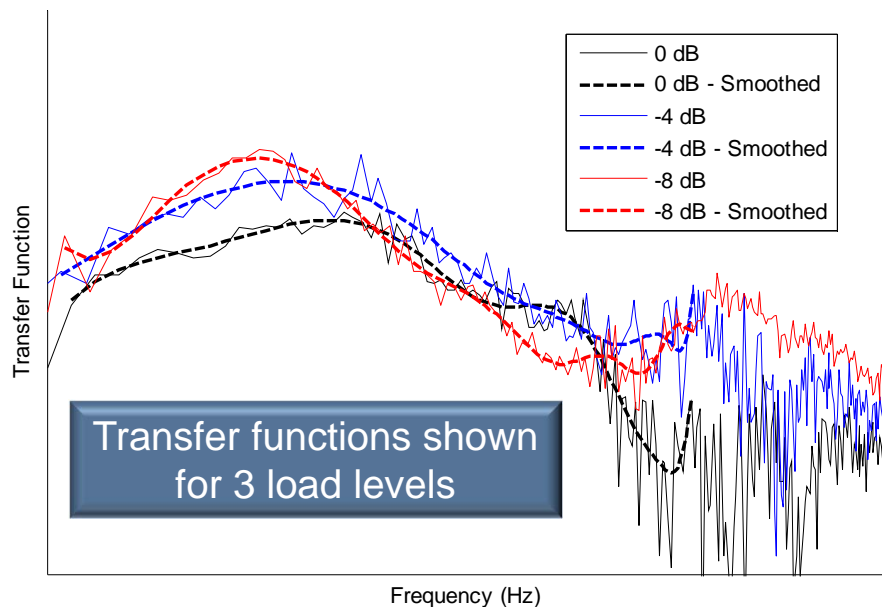
Cable Natural Frequency and Damping



Cable accelerometer / load cell accelerometer transfer functions used to identify natural frequencies

- Transfer function “smoothed” using polynomial fit then natural frequency and dynamic amplification (Q) were based on peak value of smoothed function
 - Natural frequency = frequency at smoothed peak; Q = amplitude of smoothed peak
- Natural frequency and Q plotted – grouped by parameters with strongest influence
- Test did not identify longitudinal cable modes

Suite 2: Transfer Function Plots (H2) - A008 (g) / A003Y (g)



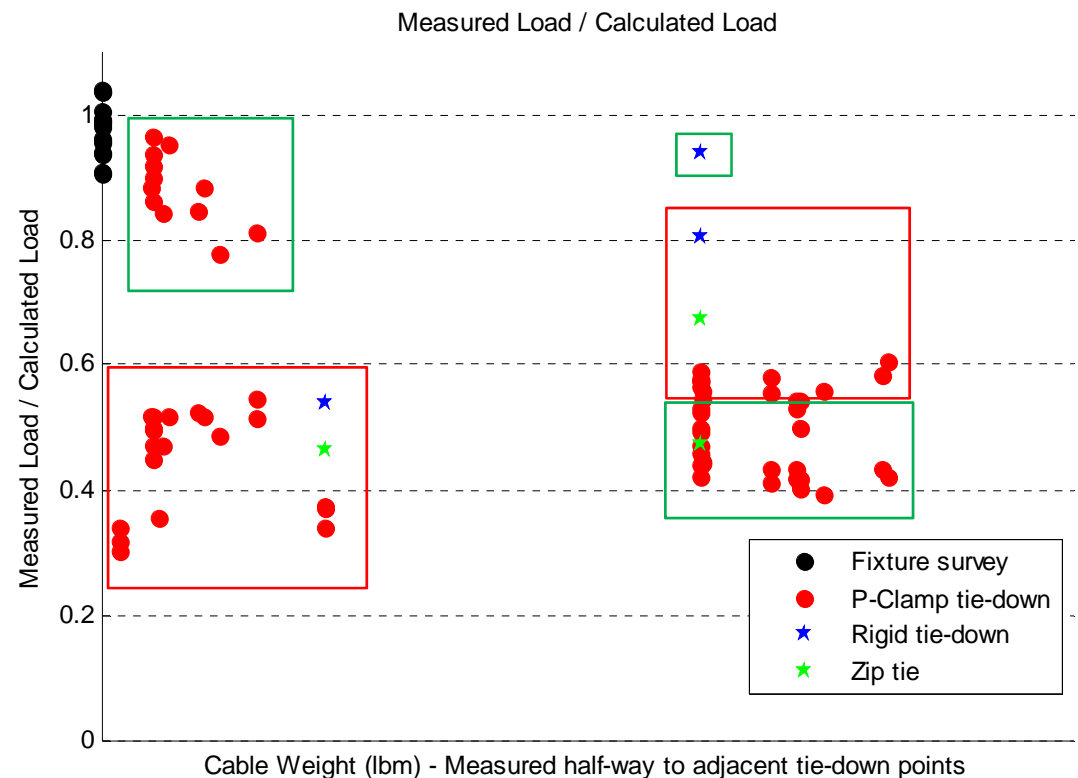
Cables have low natural frequencies, especially as tie-down spacing increases, and high damping

Development of Load Methodology



Development of methodology for calculating loads at cable tie-down points

- Measured frequency, damping, and load information used to guide development of load calculation methodology
- Methodology tested by comparing calculated loads against measured loads
- Methodology adjusted until comparison with measured loads was adequately conservative
- Plot compares calculated and measured loads for all tested cable configurations
 - Ratio < 1.0 indicates conservative methodology
 - Red boxes group radial / tangential direction configurations
 - Green boxes group longitudinal direction configurations



Load methodology developed which is conservative for all tested configurations

Load Methodology at Cable Tie-Down Points



Methodology for developing design loads at cable tie-down points

- Cable longitudinal direction:
 - Static equivalent cable load is proportional to g-rms of random vibration environment
- Cable radial / tangential directions:
 - Use Mile's equation with lower Q and cable frequencies that are a function of tie-down spacing
- G-loads at cable tie-down points are applied to the cable mass half-way to the adjacent tie-down points

Mile's equation:

$$Load[g] = 3 * \sqrt{\frac{\pi}{2} * Q * f_n * ASD}$$

Q = dynamic amplification factor

f_n = component natural frequency

ASD = acceleration spectral density at natural frequency

Methodology for generating loads at cable tie-down points with significantly reduced conservatism

Conclusions

- Preliminary testing of cables was successful
 - Fixture and instrumentation are adequate for final testing
 - Most significant variables affecting loads were identified for final testing
 - 1) Attach hardware, 2) cable orientation, 3) cable size, and 4) tie-down spacing
 - Preliminary test data was used to justify significant reduction in cable loads
 - Reduction due to higher damping assumption (reduced Q)
 - Additional reduction due to understanding of cable natural frequencies

Forward work

- Follow-on cable testing planned for summer of 2013
 - Testing to include more cable sizes, cable bundles, and additional tie-down spacing levels, based on designs
 - Test results will be used to re-evaluate cable load generation methodology
 - Testing expected to justify removal of additional loads conservatism